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DISCARD/REPAIR COST MODEL
REPAIR VERSUS THROWAWAY
PRINTED CIRCUIT CARDS AND MODULES

by

Raymon S. Dotson

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U.S. ARMY MISSILE COMMAND
Redstone Arsenal, Alabama 35898

Systems Analysis Division
Systems Analysis and Evaluation Office
U.S. Army Missile Command
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Discard versus repair policies have been subjected to numerous studies in attempt to prove or disprove the specific policy. This study is an attempt to revise and develop a model in which total parameters involved may be considered. For example, acquisition cost is a single parameter against which total cost of repair may be played in a model. This is true since once an item is repaired and returned to the pipeline it is subjected to the same cost effects as a newly acquired item.

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20. This report discusses the total cost of repair to include the return of unserviceable items to a repair facility, test and repair of the items, and return as serviceable to the pipeline. The parameters involved are discussed in a decision model. as

$$\text{Cost of Acquisition} \leq \text{per repair cost}\left(\frac{1}{A}\right) + \frac{\text{Fixed Cost}}{\text{Expected No. of Failures}}\left(\frac{1}{AB}\right)$$

Where: A is the percent of items repaired at the repair depot

B is the percent of items returned and received at the repair depot

The objective of the decision model is to determine cost effectiveness of discard or repair and establish policy. A spin-off of the model is that analysis of output against real time data permits determination of effectiveness of earlier decisions as well as examination of system effectiveness in meeting reliability goals.

ABSTRACT

For a number of reasons, among them the increasing costs of test equipment and program test sets, throwaway versus repair studies are being made to prove or disprove the specific policy. Because of numerous requests for model improvement, this study is to upgrade the Systems Analysis Repair Cost (SARC) model developed in 1971 and updated in 1973 and 1975. Additional parameters for test program sets and maintenance have been added.

This report discusses the total cost of repair to include the return of unserviceable items to a repair facility, repair of the items, and return as serviceable to the pipeline. The parameters involved are discussed in a decision model as

$$\text{Cost of Acquisition} \leq \text{per repair cost}\left(\frac{1}{A}\right) + \frac{\text{Fixed Cost}}{\text{Expected No. of Failures}}\left(\frac{1}{AB}\right)$$

Where: A is the percent of items repaired at the repair depot.

B is the percent of items returned and received at the repair depot.

The objective of the decision model is to determine cost effectiveness of throwaway or repair and establish policy. A spin-off of the model is that analysis of output against real time data permits determination of effectiveness of earlier decisions as well as examination of system effectiveness in meeting reliability goals.

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DISCARD/REPAIR COST MODEL
(DIREC)

Section I. SUMMARY

In view of the current considerable interest in throwaway versus repair, this study is to update the MICOM Systems Analysis Repair Cost (SARC) Model. This model was developed in 1971 and updated in 1973 and 1975. Since that time, several changes in procedure have occurred which require model revisions. The major changes have been the advent of Test Program Sets (TPS), greater automation of test equipment and procedures and greater use of multi-layer/microminature components. The SARC model has been upgraded and is re-named the Discard/Repair Cost (DIREC) Model, an acronym which more properly describes the model.

This study analyzes the relative merits of discard versus repair, throwaway versus repair and the problem of optimum response, both in the current and future environment. The DIREC model is presented using projective data introduced to develop cost effective solutions. The model is developed in the repair environment wherein total parameters involved may be considered. An example, acquisition cost is a single parameter against which total cost of repair may be examined in the model. This is because once an item is repaired and returned to the pipeline it is subjected to the same cost effects as a new procurement item. This study eveluates the total cost of repair, including return of unserviceables to the repair facility, test and repair, retest, and return as serviceable to the pipeline. The objective of DIREC is a decision model which will determine cost effectiveness of discard or repair and to establish policy.

It was concluded that:

1. The general model displayed in Section III will provide a tool to approximate cost effectiveness of a discard or repair policy. The operational model, as displayed in Section IV, with real time data proves or disproves accuracy of the general model inputs.

2. From a cost effectiveness standpoint, the Product Manager should establish throwaway or repair on all cards and modules as shown in Table VII. Also he should conduct an engineering study on high failure circuit cards with the objective of identifying components with low reliability and upgrade these components to provide a lower failure rate. For those circuit cards currently cost effective for repair, the objectives should be to upgrade components to provide failure rates that equalize cost of repair and acquisition to permit a discard policy. If upgrading components does not prove satisfactory, discard/repair policy should be reassessed.

Section II. INTRODUCTION

Purpose of Analysis.

This study is to determine the relative merits of throwaway versus repair of replaceable circuit cards and modules. The study embraces the problem of optimum response, both in the current and future environment. To this end a repair cost model is presented through which projected data may be introduced to develop cost effective solutions.

Background.

The SARC model was designed to determine validity of discard/repair policies for circuit cards and modules. The model was very effective in developing cost effective policies for the AN/GSA-77 Battery Test Equipment (BTE), Land Combat Support System (LCSS), Guided Missile Air Defense System AN/TSQ-73 and a number of lesser systems. On the BTE and LCSS, follow-on analysis was conducted to validate recommendations. In all cases the decisions were verified.

This report developed cost to repair data and concluded:

a. Discard/Repair of circuit cards shown in Table VII is economically justifiable and desirable. Technical feasibility has been proven by the Maintenance Engineering Directorate Missile Logistics Center based on preliminary studies in this area.

b. The test equipment recommended in this study is capable of testing all of the circuit cards with nearly 100% confidence level. This test equipment may also be modified or expanded to take on new or special assignments for other digital or linear circuits of other systems.

c. The effect of discard/repair program would be very little. Fielded systems would be maintained as present, either discard defective cards in the field or cards would be turned in for depot repair.

d. A depot repair program would replenish depot stock. With such a program, depot shortages should never occur, due to the ability of a depot to quickly produce serviceable assets from unserviceable items on an as-needed basis.

3. Development of Repair Cost Parameters

Most studies of discard/repair decision are not complete in development of parameters. They only partially present per repair and fixed costs and, therefore, fall short in presenting the total cost. An example is the tendency to ignore test equipment, test equipment repair, administrative and inventory costs as "sunk costs." The model must include all costs to return the unserviceable item to the depot, perform test and repair functions and deliver the repaired serviceable item to the distribution depot.

4. Development of the Model

The DIREC model contains the same parameters as the SARC model plus Test Program Sets (TPS) and TPS maintenance. Therefore the DIREC model is essentially the same as SARC with input data updated to current costs. The following is the basic decision model. Estimated cost of TPS's is shown in Table 1.

$$\text{Cost of Acquisition} \leq \text{per repair cost} \left(\frac{1}{A}\right) + \frac{\text{Fixed cost}}{\text{Total No. of Failures}} \left(\frac{1}{AB}\right)$$

Where: A = fraction of cards successfully repaired.

B = fraction of failed cards sent to the repair depot.

Where cost of acquisition exceeds repair, repair would be indicated. Where cost of repair exceeds acquisition, discard would be indicated.

In development of the DIREC model, several differences from the SARC model may be noted --- the parameter identification may not be the same in some cases. The parameter identification is an individual choice. The author has taken license to identify these by terms with which are more familiar. Parameters considered in this study are shown in Table II.

5. Validity of Input Data.

Every effort has been made to obtain the best and most up-to-date quantitative data possible for manipulation in the model. Sources of data such as Table III are shown as well as changes effected for validation. Insofar as possible the operational model contains real time data based on actual repair effort. Since the system is in the deployment phase, some estimates had to be made. These were particularly important in development of labor manhours as shown in Table IV. In other cases where data could not be gathered from Army sources, Industry or other source material was used. The standard inputs to the Logistic Analysis Model (LOGAM) were most useful.

TABLE I

AVERAGE COST FOR TEST PROGRAM SETS FOR FAULT
ISOLATION AND ACCEPTANCE OF PCB's

	NO DIFFERENT PARTS PER PCB				
	1-10	11-50	51-150	151-250	250-UP
SINGLE SIDE	3-5K	6-10K	11-20K	21-35K	36-55k
DUAL SIDE	3-5K	6-15K	16-30K	31-60K	61-90K
MULTIPLE SIDE	3-5K	6-15K	16-35K	36-75K	76-110K

NOTE: NOT TO EXCEED COSTS FOR COMPLEX BOARDS

TABLE II. REPAIR COST PARAMETERS

PARAMETER	MODEL		
	SARC	DEPOT	DIREC
Per Repair Cost			
Piece Parts	YES	YES	YES
Depot Labor	YES	YES	YES
Requisition	YES	NO	YES
Transportation and Handling	YES	NO	YES
Fixed Costs			
Entering and Maintaining Line Item in Inventory	YES	NO	YES
Test and Maintenance Equipment	YES	YES	YES
Maintenance of Equipment	YES	YES	YES
Test Program Sets	NO	NO	YES
Test Program Maintenance	NO	NO	YES
Technical Publication	YES	NO	YES
Test Manpower Training	NO	NO	YES

TABLE III. ADMINSTRATIVE COSTS TO ENTER AND MAINTAIN A LINE ITEM IN INVENTORY. (10 YEAR LIFE CYCLE)

ADMINISTRATIVE COSTS	DOLLARS
Oversea supply control	289.32
CONUS supply control	434.40
CONUS administrative cost of procurement	1048.01
Initial cataloging and technical research	903.31
Cost attributable to entering new item to supply system	2675.04
Continuing cataloging	2335.33
Net additional worldwide transportation	436.70
CONUS field receipt, storage, issue and stock control	239.20
Overseas receipt, storage, issue and stock control	3422.25
CONUS depot receipt, storage, issue, stock control, condemnation and disposal	5114.97
Continuing cost of procurement	1973.11
DA Staff, AGO publications, increased supervision, training, waste and increased investment	2792.54
Cost attributable to maintaining item in inventory	16314.10
ANNUAL COST TO ENTER AND MAINTAIN ITEM IN INVENTORY	1898.91

TABLE IV. LABOR MANHOURS

FUNCTION	Gp Ip	IIs	IIIs	IVs	Vs	VId	VIId	VIIId	IXd	Xm	XIm	XIIm	XIIIm
	TIME IN MINUTES												
PRELIMINARY REPAIR UNPACK/LOG IN/DETERMINE REPAIRABILITY (VISUAL)/ SCHEDULE REPAIR	10	10	12	15	15	12	15	18	18	15	18	20	20
INSPECTION SET UP TEST EQUIPMENT/CHECK SPECIFICATIONS/ DETERMINE FAULTY COMPONENTS	12	15	22	33	45	25	33	48	55	48	64	95	100
ORDER PARTS REQUISITION AND RECEIPT/STORAGE/LOCATE AND DELIVER	15	15	20	20	20	15	20	20	20	15	20	20	20
PERFORM REPAIR REMOVE CONFORMATIVE COATING/REMOVE SOLDER/REMOVE FAULTY PART/INSTALL NEW PART/SOLDER/CHECK REPAIR	20	35	95	195	245	55	130	265	325	80	148	330	395
ACCEPTANCE TEST SET UP TEST EQUIPMENT/REVIEW PERFORMANCE SPECIFICATIONS/PERFORM ACCEPTANCE TESTS/ REPLACE CONFORMAL COATING	8	12	20	24	30	20	30	36	40	35	60	70	75
ADMINISTRATIVE CHECK OUT PACKAGE LOG OUT RETURN TO STOCK	10	10	15	15	15	10	15	15	15	10	15	15	15
NOTE: THE TIMES CLAIMED ARE AN AVERAGE OF THE MAJORITY OF CIRCUIT BOARDS, PROCESSED. HIGHLY COMPLEX BOARDS MAY EXCEED THE TIMES CLAIMED.													
TOTAL MINUTES	75	97	184	302	370	137	243	402	473	203	325	550	625
TOTAL HOURS (.00)	1.25	1.61	3.07	5.03	6.17	2.28	4.05	6.70	7.88	3.38	5.41	9.17	10.41

Gp Ip	POWER SUPPLIES
Gp IIs	SINGLE SIDE BOARDS 1–10 COMPONENTS
Gp IIIs	SINGLE SIDE BOARDS 11–50 COMPONENTS
Gp IVs	SINGLE SIDE BOARDS 51 + 150 COMPONENTS
Gp Vs	SINGLE SIDE BOARDS 151 + COMPONENTS
Gp VId	DUAL SIDE BOARDS 1–10 COMPONENTS
Gp VIId	DUAL SIDE BOARDS 11–50 COMPONENTS
Gp VIIId	DUAL SIDE BOARDS 51 + 150 COMPONENTS
Gp IXd	DUAL SIDE BOARDS 150 + COMPONENTS
Gp Xm	MULTILAYER BOARDS* 1–10 COMPONENTS
Gp XIm	MULTILAYER BOARDS* 11–50 COMPONENTS
Gp XIIm	MULTILAYER BOARDS* 51 + 150 COMPONENTS
Gp XIIIm	MULTILAYER BOARDS* 150 + COMPONENTS

* 3–6 LAYERS

Section III. DISCARD/REPAIR COST GENERAL MODEL

1. Basic Considerations

The objective of the DIREC model is to provide the Engineer/Logistician with a means to arrive at an economic decision regarding discard or repair of replaceable circuit cards and modules. The model permits manipulation of various cost and related repair factors to see how these factors affect life cycle costs.

For the purposes of the study, the cost to acquire a new item is the procurement cost. Administrative costs for maintaining the item in inventory are not included since these costs apply equally to the reparied item once it is returned to stock. The cost to repair is the toal cost to return the unserviceable item to the depot, perform test and repair functions, and deliver the serviceable repaired item to the distribution depot.

The decision to repair or throw away failed circuit cards and modules is based on a comparison of costs to implement each alternative. If it is more economical to repair a particular card type, the card should be repaired. Conversely, if it is more economical to discard the failed card, it should be thrown away and replaced by a new card. The basic decision model is as follows:

$$\text{Cost of Acquisition} \leq \text{per repair cost}\left(\frac{1}{A}\right) + \frac{\text{Fixed Cost}}{\begin{array}{c}\text{Expected No.}\\ \text{of Failures}\end{array}}\left(\frac{1}{AB}\right) \qquad (1)$$

Where: A is the percent of items repaired at the repair depot.

B is the percent of items returned and received at the repair depot.

Per repair costs are those which are independent of the number of cards to be repaired and include:

C_p - Cost of piece parts per repair.

R - Depot labor rate.

M - Mean labor time.

R_C - Requisition cost.

T_C - Transportation and handling cost.

The per repair cost (PRC) portion of the equation is:

$$PRC = C_p + RM + R_C + T_C \qquad (2)$$

Fixed costs are those which will be amortized over the number of repaired cards and include:

- N_I - New line items (repair spares for inventory).
- I_C - Annual cost to enter and maintain a line item in inventory.
- L - Life of System in years.
- E_C - Special test and maintenance equipment cost.
- E_M - Test Equipment maintenance cost.
- P_S - Test Program Set cost.
- P_M - Test Program Maintenance cost.
- P_C - Technical publications.
- E_T - Test/Repair Manpower Training.

The fixed cost (FC) portion of the equation becomes:

$$FC = N_I(I_C L) + E_C(1+E_M L)+P_S(1+P_M L)+P_C+E_T \quad (3)$$

The number of circuit cards or modules which may be expected to fail over the life of the system is developed by the following equation:

- λ - Failure rate per card type per million hours.
- Q - Quantity of card type per system
- S - Number of systems for analysis.
- O - Average system operational time.
- L - Life of system in years.

Therefore, the total number of each card type or module which will be expected to fail over the life span of the system is:

$$\left(\frac{8760}{10^6}\right)\lambda QSOL \quad (4)$$

2. General Equation of the DIREC Model.

By combining the per-repair cost, fixed cost, and failure equation into the general equation (1) we have a repair cost (RC) model.

$$RC = (C_P+RM+R_C+T_C)\frac{1}{A} + \left[\frac{N_I(I_C L)+E_C(1+E_M L)+P_S(1+P_M L)+P_C+E_T}{8760(10^{-6})\,\lambda QSOL}\right]\frac{1}{AB} \qquad (5)$$

Application of data, generated for new equipment, in this model will provide the total repair cost for each item. The repair cost input data to be developed for use in the model is defined as follows:

(a) Cost of Piece Parts per Repair (C_P). Based on part count and failure rates for components, the per-repair piece part cost for the item is developed into a dollar figure.

(b) Depot Labor Rate (R). Direct labor rate of the depot to perform repair should be used. If this rate is not available, estimates may be based on local rates.

(c) Mean Labor Time (M). This includes all effort that must be expended at the repair facility from arrival until the item is repaired and returned to inventory.

(d) Requisition Cost (R_C). The average cost to process a requisition times the number of requisitions estimated to be processed per repair action.

(e) Transportation and Handling Cost (T_C). Cost external to the repair depot. These involve costs to pack, document, and transport the unserviceable item to the repair facility.

(f) Attrition Factor (A). The fraction of items arriving at the repair facility expected to be repaired and returned to stock.

(g) New Line Items (N_I). The average number of new line itmes expected to be required per type of assembly to perform the repair function.

(h) Annual Cost to Enter and Maintain a Line Item in Inventory (I_C).

(i) Life of Item (L). Length of time (in years) the item is expected to be retained in inventory.

(j) Special Test and Maintenance Equipment and Facility Cost (E_C). The acquisition cost of the equipment and facilities necessary to perform repair.

(k) Test Equipment and Facilities Maintenance Cost (E_M). Estimate of cost of maintenance in percent of acquisition cost per annum. Industry or government experience factor may be used.

(l) Technical Publication Cost (P_C). Costs involved in developing technical instructions for repair of the item.

(m) Repairable Failed Cards (B). Based on number of unserviceable items generated, a number would not be returned due to being non-repairable or lost in the pipeline. Those likely to be received at the repair depot determine this factor.

(n) Number of Major Items (S). The number of systems in the analysis for which the item to be repaired is a component.

(o) Failure Rate (λ). The failure rate per million hours is developed for the item based on such factors as government or industry specifications, actual experience, like item experience, or reliability data.

(p) Quantity of Item per System (Q). The number of like items included in the same system.

(q) Average System Operational Time (O). The percent of time the system is operated, i.e., eight hours per day 5 days per week = 0.24. Sixteen hours per day 7 days per week = 0.67.

3. Interpretation of Failure Data.

The above equation can be used prior to field experience with the system to determine decisions to repair or throw away components. If the analysis shows the cost of repair is within 20 percent of the cost of procuring a replacement item, then either method is used. When the cost difference exceeds 20 percent, the more economical method is used.

Once field experience has established replacement data, λ may be developed utilizing actual failure rates. In this event the denominator of equation (5) is revised as follows:

$8760(10^{-6})$, quantity of items per system (Q), and average operational time (O) are replaced by computing λ as a percent of actual failures per system. Thus the denominator of equation (5) becomes

$$\lambda LS \tag{6}$$

Therefore the specific equation for throwaway versus repair for an item with actual operation data becomes:

$$RC = (C_P+RM+R_C+T_C)\frac{1}{A} + \left[\frac{N_I(I_C L)+E_C(1+E_M L)+P_S(1+P_M L)+P_C}{\lambda LS} \quad \frac{1}{AB}\right] \tag{7}$$

Section IV OPERATIONAL MODEL

1. Introduction.

Recently there has been an increase of interest in discard versus repair due to the realization that test equipment, test programs, maintenance manpower costs, and administration cost of repair have caused repair costs to rise at increasing rates. It can be supported that if a circuit card costs $500.00 to procure and has an average failure rate, it should be thrown away. Also if an expensive card costing $15,000.00 has a very low failure rate, it should be thrown away. Because of the complexities of determining this discard/ repair decision, the DIREC model has been developed to provide a viable means for decision.

2. Repair Cost Input Data.

The repair cost input data shown in Tables V, Va, VI, and VIa can now be quantified based on data developed from various sources. Repair cost input data is expressed as follows:

a. Cost of Piece Parts per Repair (C_p).

Based on 24 cards and 4 modules in this study, piece parts were costed by reviewing the type of component, its price and its reliability. Using industry standards, part count, and failure rates, cost of piece parts for each group were established. Source: Industry standard reliability tables and work breakdown structure of each circuit card and module.

b. Depot Labor Rate (R).

Direct labor rate at Depot level is established at $32.60 per hour. Source: Tooele Army Depot Manpower Rate, June 1984.

c. Mean Labor Time (M).

Analysis of labor requirements to repair each circuit card type are shown in Table IV. Source: Sacremento Army Depot, 25 May 1984. See Appendix for circuit card repair process.

d. Requisition Cost (R_C).

Assumption is made that one requisition is processed per repair action. $24.30 per requisition is used for this study. Source: Depot Maintenance Study, May 1984.

e. Transportation and Handling Cost (T_C).

Cost to package, document, and transport cards back to the depot for repair. Since this cost is additional over throwaway policy, cost used for this study is $44.00 per item. Source: Table III -- $43.67 for net additional transportation is used. $43.67 is rounded to $44.00.

TABLE V. MODEL INPUT DATA

GROUP II_S

IDENTIFICATION	Parts Count	λ	Annual Failures	C_P	R	M	R_C	T_C
CCA 13099729	5	.534	2871	588	33	1.61	24	44
CABLE 868003	3	1.113	5983	1633	33	1.61	24	44
CABLE 13099870	3	1.113	5983	306	33	1.61	24	44

GROUP III_S

POST AMP 1	11	.08	430	127	33	3.07	24	44
POST AMP 2	11	.093	500	132	33	3.07	24	44
CCA 13099732	11	.018	97	31	33	3.07	24	44
CCA 967947	27	.036	194	52	33	3.07	24	44

GROUP IV_S

CCA 13099736	62	1.113	5983	31	33	5.03	24	44
CCA 13099739	69	.107	575	32	33	5.03	24	44
CCA 13099744	56	.08	430	25	33	5.03	24	44
CCA 13099747	60	.098	527	21	33	5.03	24	44
CCA 13099755	74	.031	167	8	33	5.03	24	44
CCA 13099764	69	.027	145	10	33	5.03	24	44
CCA 13099825	107	.007	38	10	33	5.03	24	44

TABLE Va. MODEL INPUT DATA

GROUP XII_M

IDENTIFICATION		Parts Count	λ	Annual Failures	C_P	R	M	R_C	I_C
CCA	13099752	109	.04	215	19	33	9.17	24	44
CCA	13099770	142	.04	215	12	33	9.17	24	44
CCA	13099777	108	.025	134	8	33	9.17	24	44
CCA	13099793	97	.045	242	9	33	9.17	24	44
CCA	13099801	133	.036	194	9	33	9.17	24	44

GROUP $XIII_M$

CCA	13099758	157	.022	118	10	33	10.41	24	44
CCA	13099761	252	.053	285	8	33	10.41	24	44
CCA	13099767	190	.027	145	8	33	10.41	24	44
CCA	13099805	190	.022	118	7	33	10.41	24	44
CCA	13099809	162	.076	409	7	33	10.41	24	44
CCA	13099813	168	1.513	8134	9	33	10.41	24	44
CCA	13099817	169	.04	215	9	33	10.41	24	44
CCA	13099821	164	.018	97	9	33	10.41	24	44
CCA	13099831	192	.049	263	7	33	10.41	24	4[illegible]

TABLE VI. MODEL INPUT DATA

GROUP II_S

IDENTIFICATION	N_I	I_C	E_C	E_M	P_S	P_M	P_C	E_T
CCA 13099729	1	1898.91	465510.00	46551.00	7700.00	385.00	5040.00	130457.00
CABLE 868003	1	1898.91	970090.00	97009.00	6300.00	315.00	5040.00	270234.00
CABLE 13099870	1	1898.91	970090.00	97009.00	6300.00	315.00	5040.00	270234.00

GROUP III_S

IDENTIFICATION	N_I	I_C	E_C	E_M	P_S	P_M	P_C	E_T
POST AMP 1	1	1898.91	108450.00	10845.00	11900.00	595.00	5040.00	32614.00
POST AMP 2	1	1898.91	126609.00	12660.90	11900.00	595.00	5040.00	37274.00
CCA 13099732	1	1898.91	24464.00	2446.00	11900.00	595.00	5040.00	9318.00
CCA 967947	2	1898.91	48929.00	4892.00	18900.00	945.00	5040.00	13978.00

GROUP IV_S

IDENTIFICATION	N_I	I_C	E_C	E_M	P_S	P_M	P_C	E_T
CCA 13099736	6	1898.91	2047891.00	204789.00	12740.00	637.00	5040.00	568422.00
CCA 13099739	6	1898.91	196814.00	19681.40	14210.00	711.00	5040.00	55910.00
CCA 13099744	5	1898.91	147183.00	14718.30	11550.00	577.00	5040.00	41933.00
CCA 13099747	6	1898.91	180384.00	18038.40	11480.00	574.00	5040.00	51251.00
CCA 13099755	7	1898.91	57162.00	5716.20	23660.00	1183.00	5040.00	18637.00
CCA 13099764	6	1898.91	49631.00	4963.10	14210.00	711.00	5040.00	13978.00
CCA 13099825	10	1898.91	13007.00	1300.70	21980.00	1099.00	5040.00	4659.00

TABLE VIa. MODEL INPUT DATA

GROUP XII_M

IDENTIFICATION	N_I	I_C	E_C	E_M	P_S	P_M	P_C	E_T
CAA 13099752	10	1898.91	213027.00	21302.70	30520.00	1526.00	5040.00	60570.00
CAA 13099770	11	1898.91	213027.00	21302.70	43750.00	2188.00	5040.00	60570.00
CAA 13099777	10	1898.91	137771.00	13277.10	30240.00	1512.00	5040.00	37274.00
CAA 13099793	10	1898.91	239780.00	23978.00	27160.00	1358.00	5040.00	65229.00
CAA 13099801	11	1898.91	192220.00	19222.00	37240.00	1862.00	5040.00	51251.00

GROUP $XIII_M$

13099758	12	1898.91	124145.00	12414.50	43960.00	2199.00	5040.00	37274.00
13099761	17	1898.91	299842.00	29984.20	77616.00	3881.00	5040.00	83866.00
13099767	12	1898.91	152551.00	15255.10	58520.00	2926.00	5040.00	41933.00
13099805	12	1898.91	124145.00	12414.50	58520.00	2926.00	5040.00	37274.00
13099809	12	1898.91	430299.00	43029.90	49910.00	2495.00	5040.00	121139.00
13099813	14	1898.91	8557586.00	855758.60	51100.00	2555.00	5040.00	371594.00
13099817	14	1898.91	226196.00	22619.60	52080.00	2604.00	5040.00	65229.00
13099821	14	1898.91	120051.00	10205.10	51100.00	2550.00	5040.00	27955.00
13099831	15	1898.91	276696.00	27669.60	59150.00	2957.00	5040.00	79206.00

f. Attrition Factor (A).

0.90 cards returned for repair would be returned to stock. Source: Depot Estimates. Tooele and Anniston Army Depots estimate 85 to 90 percent repair recoverability. For the purposes of this study, .90 percent returned to stock from Depot repair is used.

g. New Line Items (N_I).

Based on number of piece parts per circuit card and review of parts listed as standard in the Federal Stock Catalog, estimates by the manufacturer were verified with reasonable accuracy. N_I quantities used for this study are prorated to groups as shown in Table V. Source: Work Breakdown Drawings of actual repairable items and comparison with current national stock numbers.

h. Annual Cost to Enter and Maintain a Line Item in Inventory (I_C).

Annual cost to enter and maintain a line item is $1898.91. Source: Table III.

i. Life of System (L).

Equipment life is assumed to be 10 years.

j. Special Test and Maintenance Equipment Cost (E_C).

Equipment acquisition cost is estimated at $1,489,500. Prorated cost per card type is shown in Table VI. Source: Test equipment list recommended by prime contractor and prorated costs per card type by Systems Analysis. Based on failure rate density, and manhour requirements for test, 11.2 sets of test equipment are required.

k. Test Equipment Maintenance Cost (E_M).

Cost is estimated at 10 percent of acquisition cost per annum. Source: Industry experience with commercial test equipment.

l. Test Program Set Cost (P_S).

Cost is estimated as shown in Table VI using Table 1. Source: Ind Stds 1982.

m. Test Program Maintenance Cost (P_M).

Cost is estimated at five percent of acquisition cost per annum. Source: Depot maintenance experience with maintenance and update.

n. Test/Repair Manpower Training (E_T). Cost to train test/repair manpower is $27,183.00. 42.85 men are required per shift for two shifts per day. Retraining will be at .2 rate/man/year. For 10 years operation E_T= $4,659,166.00. Source TRADOC Training Cost Guide and Comptroller of the Army, Army Force Cost Planning Handbook.

o. Technical Publication Cost (D_C).

Technical publication generation cost is $280.00 per page. For 420 pages (15 pages per card type) the technical publication generation cost is $117,600.00. Assuming a two percent attrition of page validity per year, the

cost to maintain, revise, and update technical publications over the life of the equipment is an additional \$23,520.00 for a total publication cost of \$141,120.00. Further assuming an equal amount of pages for each card type, the prorated cost would be \$5040.00 per card type. Source: MICOM Missile Logistics Center Study, April 1983.

p. Repairable Failed Cards (B).

Based on evaluation in the field of such obvious failures as burned or broken cards, broken circuits, visual identification of major component failures and pipeline loss, it is estimated that 70 to 80 percent of all failed cards would be returned to depot repair. The B factor used for this study is the average (.75) of the field estimates. Source: Estimates of field and depot maintenance and support personnel.

q. Number of Systems (S).

5376 systems are used for this analysis.

r. Failure Rate (λ).

Annual failures per card type is shown in Table V . This quantity divided by 5376 fielded systems yields annual average failure rate (λ) system. Source: Replacement data provided by the MICOM Missile Logistics Center.

3. Construction of the Operational Model.

Based on quantitative inputs as shown in the input data above and in Tables V, Va, VI and VI a categorical model from Equation (7) is developed for each group as follows:

GROUP II_S

$$RC = (C_p + 53.13 + 24 + 44)\frac{1}{0.9} + \left[\frac{18989 + E_C(2.0) + P_S(1.5) + 5040 + E_T}{\lambda 10(5376).675}\right] \quad (8)$$

GROUP III_S

$$RC = (C_p + 101.31 + 24 + 44)\frac{1}{0.9} + \left[\frac{N_I(18989) + E_C(2.0) + P_C(1.5) + 5040 + E_T}{\lambda 10(5376).675}\right] \quad (9)$$

GROUP IV_S

$$RC = (C_p + 165.99 + 24 + 44)\frac{1}{0.9} + \left[\frac{N_I(18989) + E_C(2.0) + P_C(1.5) + 5040 + E_T}{\lambda 10(5376).675}\right] \quad (10)$$

GROUP XII_M

$$RC = (C_p + 302.61 + 24 + 44)\frac{1}{0.9} + \left[\frac{N_I(18989) + E_C(2.0) + P_S(1.5) + 5040 +}{\lambda 10(5376).675} + E_T\right] \quad (11)$$

GROUP $XIII_M$

$$RC + (C_p + 343.53 + 24 + 44)\frac{1}{0.9} + \left[\frac{N_I(18989) + E_C(2.0) + P_S(1.5) + 5040 +}{\lambda 10(5376).675} + E_T\right] \quad (12)$$

4. Repair Cost Analysis.

By introducing the cost of parts and failure rate for each card type in a group to equations (8), (9), (10), (11), and (12) the repair cost is developed. The results in Table VII indicate that 15 circuit cards of the 28 evaluated are candidates for discard and the rest are repairable.

TABLE VII. REPAIR COST EVALUATION

GROUP II_S

IDENTIFICATION	λ	Annual Failures	Acquisition Cost	Repair Cost	Discard/ Repair
CCA 13099729	.534	2871	2100	1349.06	R
CABLE 868003	1.113	5983	3500	2004.59	R
CABLE 13099870	1.113	5983	655	530.15	R

GROUP III_S

POST AMP 1	.08	430	995	429.61	R
POST AMP 2	.093	502	1035	433.38	R
CCA 13099732	.018	97	240	375.86	D
CCA 967947	.036	194	1012	386.14	R

GROUP IV_S

CCA 13099736	1.113	5983	1385	418.97	R
CCA 13099739	.107	575	1560	447.45	R
CCA 13099744	.08	430	1000	444.02	R
CCA 13099747	.098	527	905	437.48	R
CCA 13099755	.031	167	425	541.27	D
CCA 13099764	.027	145	470	529.87	D
CCA 13099825	.007	38	455	1289.04	D

TABLE VIIa. REPAIR COST EVALUATION

GROUP XII_M

IDENTIFICATION	λ	Annual Failures	Acquisition Cost	Repair Cost	Discard/ Repair
CCA 13099752	.04	215	1445	933.98	R
CCA 13099770	.04	215	1200	948.52	R
CCA 13099777	.025	134	595	1019.34	D
CCA 13099793	.045	242	645	899.72	D
CCA 13099801	.036	194	335	947.28	D

GROUP $XIII_M$

CCA 13099758	.022	118	515	1200.42	D
CCA 13099761	.053	285	1390	1052.55	R
CCA 13099767	.027	245	705	1147.65	D
CCA 13099805	.022	118	475	1224.42	D
CCA 13099809	.076	409	805	932.60	D
CCA 13099813	1.513	8134	605	828.52	D
CCA 13099817	.04	215	605	1064.36	D
CCA 13099821	.018	97	535	1354.82	D
CCA 13099831	.049	263	1005	1033.72	D

Section V. CONCLUSIONS AND RECOMMENDATIONS

1. Conclusions

a. The general model displayed in Section III will provide capability to approximate cost effectiveness of a DISCARD/REPAIR policy. The operational model shown in Section IV, with real time data will prove or disprove accuracy of the general model inputs.

b. The results in Table VII and VIIa indicate there are 15 circuit cards for which repair exceeds cost of acquisition.

2. Recommendations

a. That DISCARD/REPAIR as shown in Tables VII and VIIa be implemented as appropriate.

b. That the DIREC Cost Model described in this study be adopted as an Army standard.

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APPENDIX

Factors Considered in Evaluation of a Repair Concept

In previous evaluations made in the Land Combat Support System Printed Circuit Board Throwaway versus Repair Cost Comparison Study, the Cost Analysis Division of the Comptroller and Director of Programs, US Army Missile Command, made a number of observations. These observations evaluated the relative merit of a discard versus repair concept and explored the activities related to the repair process as follows:

a. Analysis of the Repair Process

The repair process can be broken down into 11 generalized logical steps.[1] The first step is the testing procedure to specifically identify the cause of failure; and the order of frequency of occurrence, these are: (1) failure of a component, (2) failure of an integrated circuit chip, or (3) failure due to a fault in the soldered connecting points of parts to circuit cards. In some cases, a visual inspection is sufficient to determine the point of failure, but not sufficient to determine the cause. In other cases, individual components and/or chips may be removed and tested individually or removed, replaced, and the entire card tested in a tril and error procedure until the problem is corrected.

The second step involves the removal of the epoxy conformal coating from the site of the component or chip suspected of being the point of failure. This procedure may be accomplished in two ways: (1) by cutting away the coating, or (2) by burning through the coating with a hot soldering iron. Either method, if not performed with a high level of care, can possibly degrade the function of the circuit card. The cutting process can damage the etched card pattern, or any carbon left on the card from the burning process can change the performance characteristics of the item.

The third step, after the removal of the conformal coating is desoldering the component or chip for removal. This involves heating the soldered contact points to a temperature sufficient for the solder to flow, at which point the problem chip or component may be removed.

The fourth step involves cleaning the residual solder from the contact pads of the card.

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[1]Based on discussions with the NASA Soldering Committee and an analysis of Guidelines for Printed Circuit Board Component Mounting published by The Institute of Printed Circuits. Other documenation published by NASA was also studied.

The fifth step is a visual inspection to determine whether or not the etched pattern or contact pads have been damaged during the mechanical processes to this point.

The sixth step is the preparation of the replacement component or chip for installation. For first quality workmanship, and to preclude the possibility of degradation of performance of the repaired item, several processes should be performed. These include retinning the leads of the component or chip without damage prior to installation, even though these parts are already pretinned. Tin has a tendency to transform to powdery form after the passage of time. Subsequent to this process, stress relief curves could be formed in the leads.

The seventh step is the installation of the repair part. This is a soldering process, and in the case of component replacement, involes the use of a low wattage hand soldering iron to install the part. On the other hand, if the part to be replaced is an integrated circuit chip, an impulse soldering tool should be used in order to reduce the chance of thermal damage to the chip or the board itself. Either process may induce latent defects - cold soldered contact points may fail or deteriorate over time whereas excessive heat may cause immediate damage or degrade the part so as to reduce its expected life.

The eighth step is to electronically test the repaired card to assure its proper performance after repair.

The ninth step is the application of the protective conformal coating to the repair site. This involves mixing a small quantity in critical proportions of an epoxy resin and catalyst. For top quality performance of the repaired item, this mixture should be de-aerated by placing it in a vacuum bell jar to remove air bubbles and all of this accomplished within the critical pot life of the mixture. Finally, the repaired site is recoated.

The tenth step is the curing process. The most desirable method to perform this process is oven curing, wherein temperature and humidity can be controlled.

The eleventh and last step is a quality control electronic retest of the repaired circuit card.

b. Expected Degradation of Circuit Cards Due to Repair.

None of the preceding steps in the repair process can be deleted without some measure of degradation in the subsequent performance of the repaired card. The Chairman of the Science and Engineering Soldering Committee, Marshall Space Flight Center, NASA, indicates the eleven step process is essential if repair is to be considered equal to a new circuit card. The two steps, removal and replacement, must be properly performed; however, the other nine steps are actually the most important in the maintenance of quality in the repair function. The other steps require a higher level of skill than the mechanical skills involved in simply removing and replacing a faulty component.

No data is currently available to indicate whether there is a significant difference in the performance characteristics of a repaired card as compared to a new one. In solid state electronic devices it has been found that a new item tends to break in and run indefinitely. If there is a weak component it will usually malfunction early. It is obvious, however, that if quality control in the repair process is not maintained at least to the level of the original manufacturing process, some degradation in performance characteristics can be expected. An experiment should be designed to establish the amount of this degradation if repair is established as policy.

c. Levels of Skill and Facilities Required for Repair.

The maintenance of adequate quality control in the repair process of printed circuit cards requires not only the equivalent procedures and levels of skill employed during the original manufacturing process, but also facilities must be as nearly the same as can be provided. NASA has found that white room[2] facilities of 600 to 1000 feet, and special production equipment costs can be provided for $50,000. Such facilities are sufficient for bath production of one hundred or less prototype micro-electronic circuit cards. Based on this actual experience and the fact that the capital equipment required for manufacturing is greater than that for repair, it is estimated that sufficient facilities for the repair of 20 to 40 printed circuit cards per day should not exceed this figure. Test and calibration equipment costs[3] would be in addition to this figure. Such a facility should be adequate to support the repair requirements of from 800 to 1000 BTE's in an operational status.

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[2] Proceedings of Second NASA Microelectonics Symposium, June 1967, p. 45.

[3] Test and calibration equipment could be in the form of Test Program Sets programmed to perform circuit board checkout.

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